The New NASA Solar System Roadmap & Probes to Other Worlds

G. Scott Hubbard, Director NASA Ames Research Center
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The Vision for Space Exploration

- *Implement* sustained & affordable human/robotic program to explore the solar system and beyond
- *Extend* human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations
- *Develop* the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration
- *Promote* international and commercial participation in exploration to further U.S. scientific, security, and economic interests.

Solar System Roadmap Team & Process

- **3 co-chairs**
  - Orlando Figueroa, NASA Headquarters
  - Scott Hubbard, NASA Ames Research center
  - Jonathan Lunine, University of Arizona

- **Members from government, academia, and industry:**

Dr. Meenakshi Wadhwa, The Field Museum
Dr. Torrence Johnson, JPL
Dr. Melissa McGrath, MSFC
Dr. David DesMarais, ARC
Dr. Douglas Erwin, National Museum of History
Dr. Wesley T. Huntress, Jr., Carnegie Institute of Wash.
Dr. Robert Pappalardo, Univ. of Colorado
Dr. Karen Meech, Univ. of Hawaii
Dr. Ellen Stofan, Proxemy Rresearch Inc.
Mr. John Niehoff, SAIC
Dr. Ben Clark, LMA
Dr. Andrew B. Christensen, NGST
Dr. Thomas D. Jones, Consultant
Mr. Jerry Chodil, Ball Aerospace(ret.)
Mr. Greg Davidson, NGST
Mr. Charles Whetsel, JPL
Mr. Gregg Vane, JPL
Dr. Heidi Hammell, SSI
Ms. Judith Robey, NASA HQ

Ex-Officio

Mr. Andrew Dantzler, NASA HQ
Mr. Chris Jones, JPL
Mr. Jason Jenkins, NASA HQ

Directorate Coordinator

Dr. Carl Pilcher, NASA HQ

- **Chartered as a formal US federal advisory committee**
  - All meetings open and announced in advance
  - Conclusions reached in public setting
- **White paper and overview charts presented to National Research Council on Monday, June 13, 2005**

Goals and Objective

- **Agency Goal from the Vision for Space Exploration**
  - Conduct robotic exploration across the solar system for scientific purposes and to support human exploration. In particular, explore the moons of Jupiter, asteroids, and other bodies to search for evidence of life, to understand the history of the solar system, and to search for resources.
- **Roadmap Objectives**
  - Learn how the sun's family of planets and minor bodies originated
  - Determine how the solar system evolved to its current diverse state including the origin and evolution of the Earth's biosphere
  - Explore the space environment to discover potential hazards and search for resources that would enable permanent human presence
  - Understand the processes that determine the fate of the solar system and life within it
  - Determine if there is or ever has been life elsewhere in the solar system

Roadmap Summary: Science Threads
How does a planetary system become habitable?

- **Habitability in planetary environments**
  - Earth-like planets: Venus-Earth-Mars
    - Venus is a baked dry version of Earth; they are the same size; when did Venus become uninhabitable?
    - Mars is frozen solid--did life ever start there and does life still exist?
  - Blue Moons: Europa-Titan-Triton: Another warm-to-cold trio
    - Habitable worlds around the giant planets
    - Is there life on Europa?
    - What does organic chemistry on Titan tell us about how life began?
- **Habitability in the architectures of planetary systems**
  - What can we learn form the giant planets?
    - How do giant planets determine the arrangement of terrestrial planets near the habitable zone? (focus on Jupiter & Neptune)
    - Can giant planets in the habitable zones of stars have habitable moons?
  - Comets and other impactors
    - How were the ingredients for life supplied and when?
    - How have impacts affected the survival and evolution of life through time?

(Note: This Roadmap does *not* include Moon/Mars Flight missions)

Roadmap Options and Alternatives

- **Roadmap is anchored on a budget balanced portfolio of:**
  - **Discovery, New Frontiers, Flagship class missions**
  - Robust programs of R&A
  - Critical technology developments
  - Supporting ground observations
  - EPO
- **Three categories make up the options for flight missions**
  - **Discovery ($300M to $500M)**
    - Open unrestricted competition to address broad solar system objectives
    - Budget projection supports flying 5 per decade
  - **New Frontiers ($500M to $800M)**
    - Open competition to address solar system objectives consistent with Decadal Survey recommendations
    - Budget projection supports flying 3 per decade
  - **Flagship missions ($800M to $1400M or $1400M to $2800M)**
    - Major investigation campaigns to address fundamental questions in SSE consistent with Decadal survey recommendations
    - Investigations address distant and/or extreme environments
    - Budget projection supports flying two $800-1400M or one $1400-2800M mission(s) per decade.

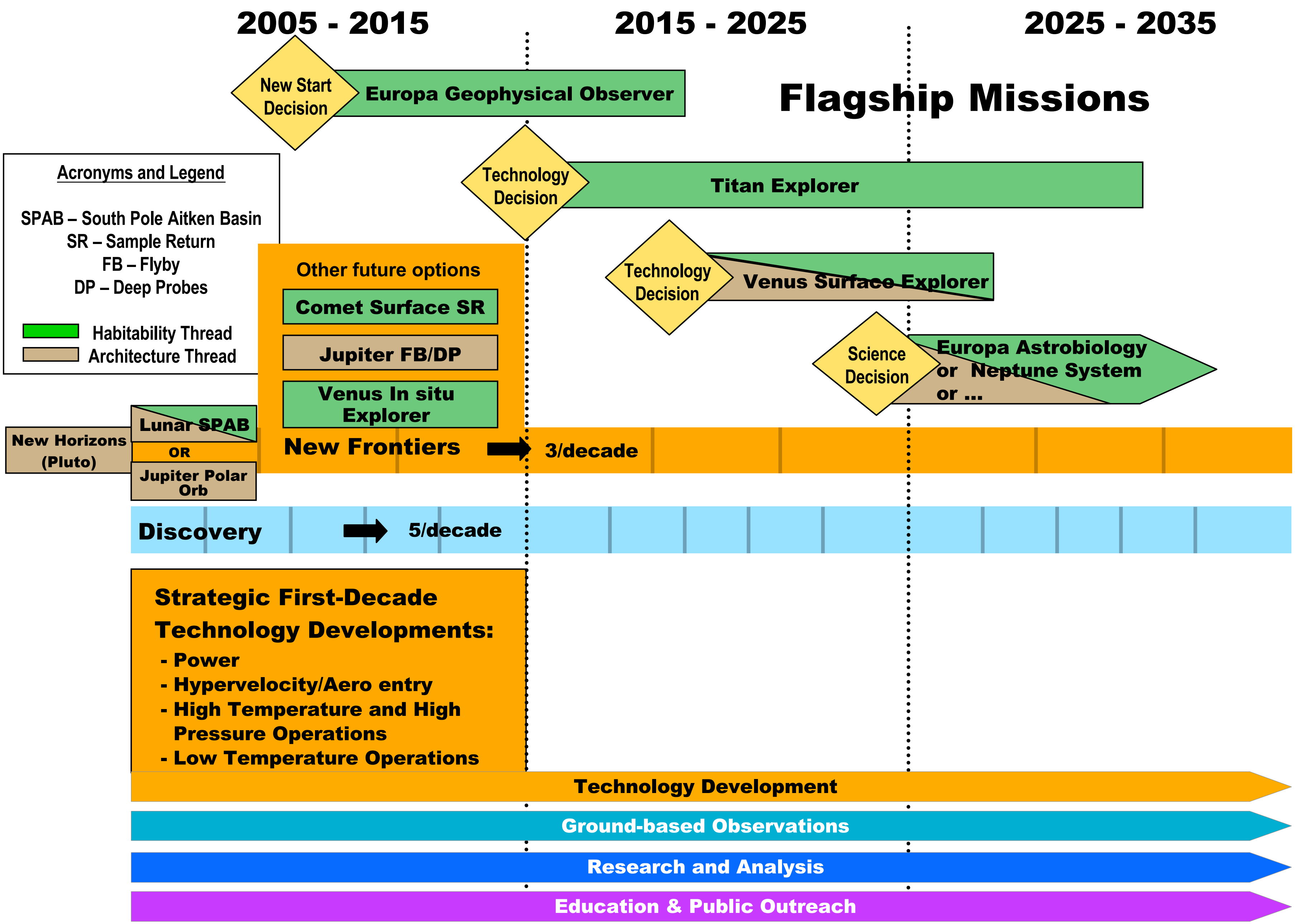
Roadmap Mission Set Options: Drawn from National Academy Decadal Survey

- **New Frontiers**
  - Kuiper Belt/Pluto
  - Lunar South Pole Aitken Basin Sample Return
  - Comet Surface Sample Return
  - Venus In Situ Explorer
  - Jupiter Polar Orbiter with Probes
- **Flagship Missions**
  - Europa Geophysical Orbiter
  - Titan Explorer
  - Venus Surface Explorer
  - Europa Astrobiology Lander
  - Neptune Orbiter with Probes
  - Comet Cryo Nucleus Sample Return
  - Venus Sample Return

Flagship Decision Criteria

- **Decision Points are influenced by the confluence of 3 major factors:**
  - Scientific priorities and knowledge
  - Technological readiness or capability
  - Programmatic considerations
- **Precursor missions influence the destination(s), the campaign architecture, and the approach**
- **Discovery and New Frontiers missions selected can influence other priorities**
- **A focused investment in critical technologies and capabilities will enable the missions, and will dictate the timetable for their implementation.**

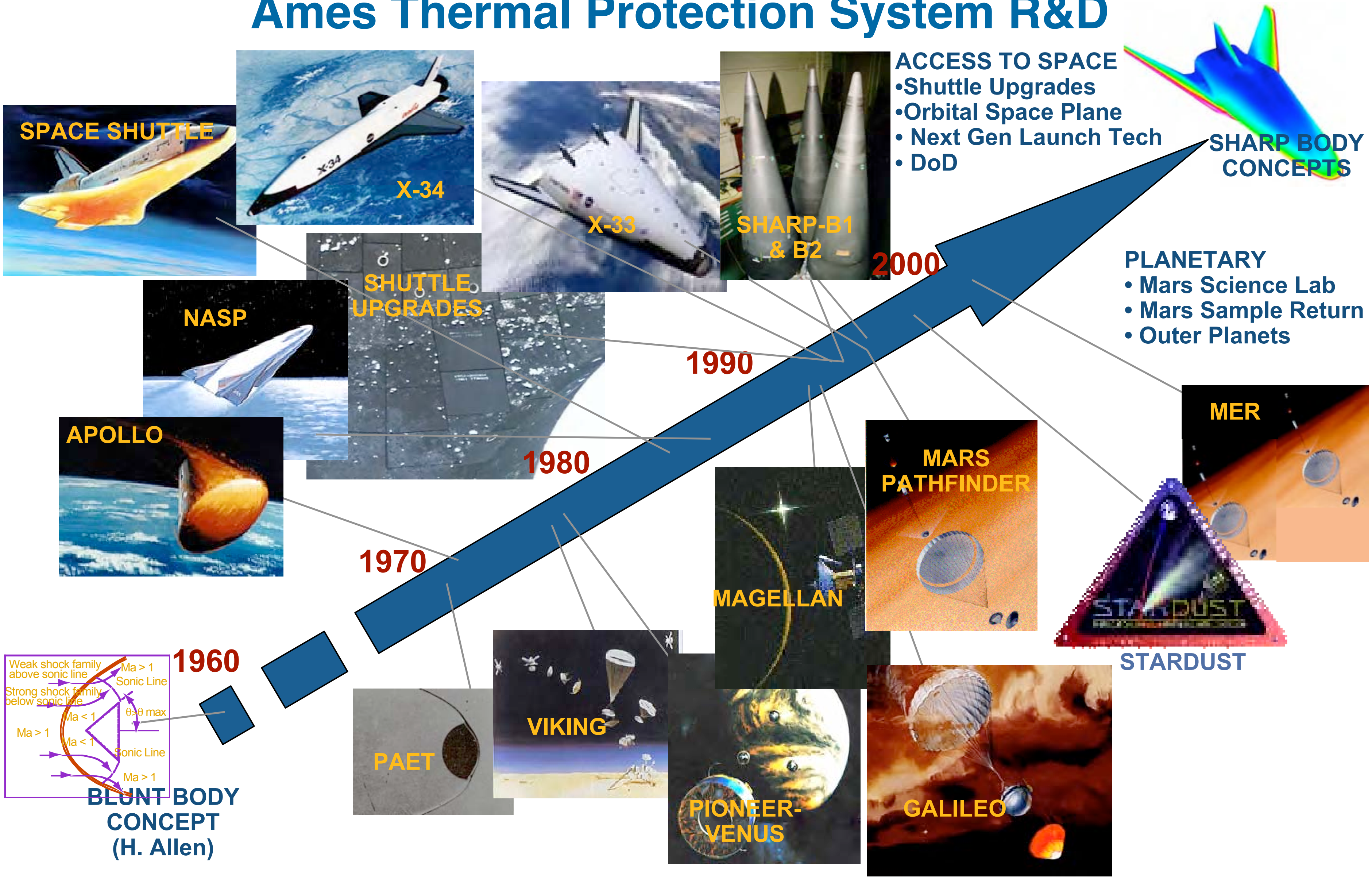
NASA Solar System Exploration Roadmap



Roadmap Requirements Technology Summary

- **Highest priority investments**
  - Radioisotope Power Source Technologies (100’s and 10’s watt high efficiency to milliwatts)
  - Technologies for extreme environments
    - High Radiation Tolerance (Europa, Jupiter)
    - Very high (Venusian surface) and very low (Titan mid-atmosphere) temperatures
    - Extreme pressure (hundreds of bars: Venus, Jupiter, Neptune)
    - Atmospheric entry probes for outer planets and Venus (very high heating rates in He/H atmosphere for outer planets and high heating rates in CO_2 for Venus)
- **Further assessment of the following technology areas**
  - Closer evaluation of optical communications, ultra-high bandwidth and ultra-high pressure communication/survival technologies which could enhance and possibly enable deep giant planet probes
  - Further study to determine specific needs for technologies in Autonomous Systems, Science Instruments, Nanotechnology or Advanced Modeling and Analysis to enhance SSE missions.

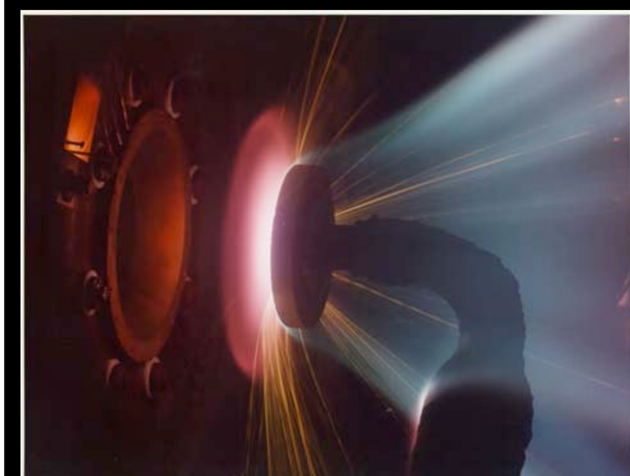
NASA Missions Enabled by Ames Thermal Protection System R&D



Thermal Protection Materials and Arc-Jet Facility

Testing and/or materials for all US Planetary and human rated entry systems.

Ames Arcjet Complex

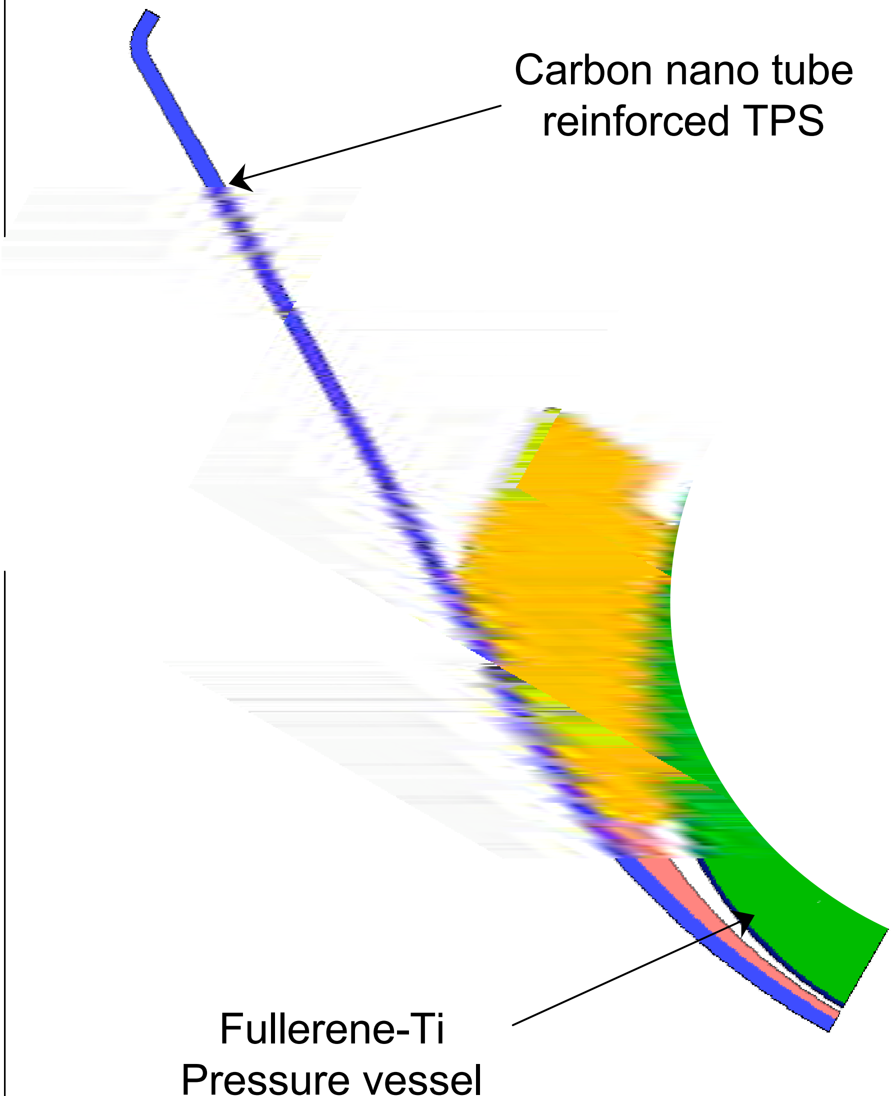


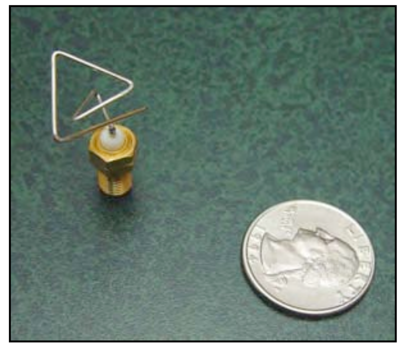
Ablative Thermal Protection Testing

Mars Rover Entry System Test

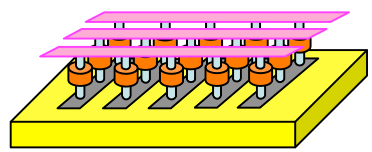
Human rated vehicle design & test

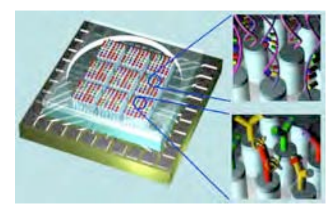
Projected Enabling Technologies for Pico/Nano Probes




Evolved antennas

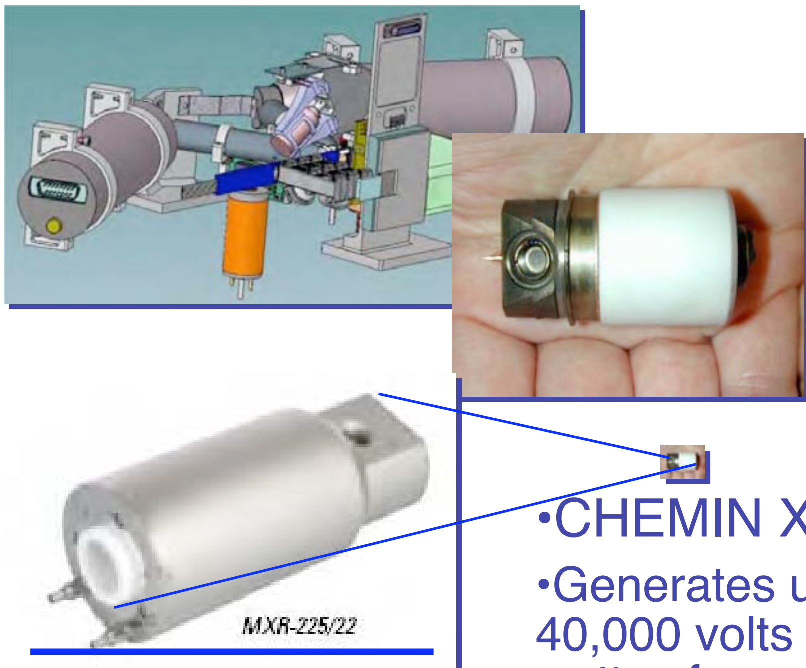

Passive heat pipes


Nano electronics


Nano sensors

Technology Enabling NASA's Missions

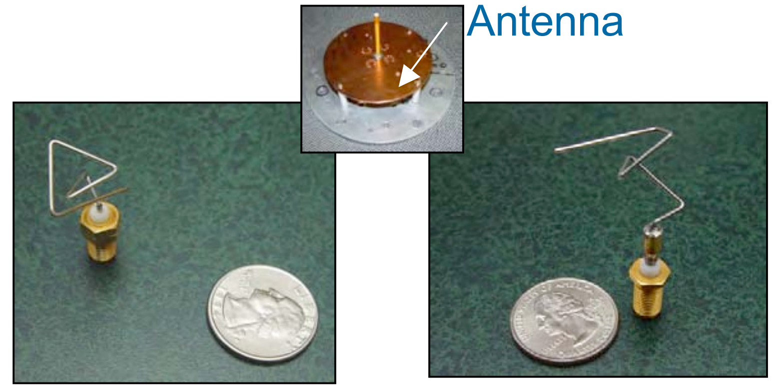
- CHEMIN X-Ray Diffraction instrument for Mars '09



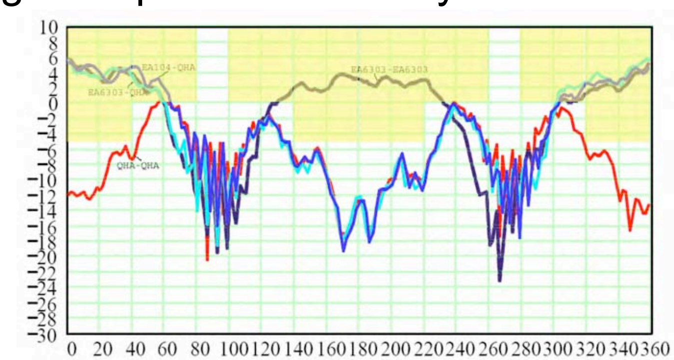
- **Traditional X-ray tube= ~ 12"**

- CHEMIN X-ray tube
- Generates up to 40,000 volts with <10 watts of power

Conventional Antenna



2nd generation evolved antenna based on changed requirements will fly on ST 5

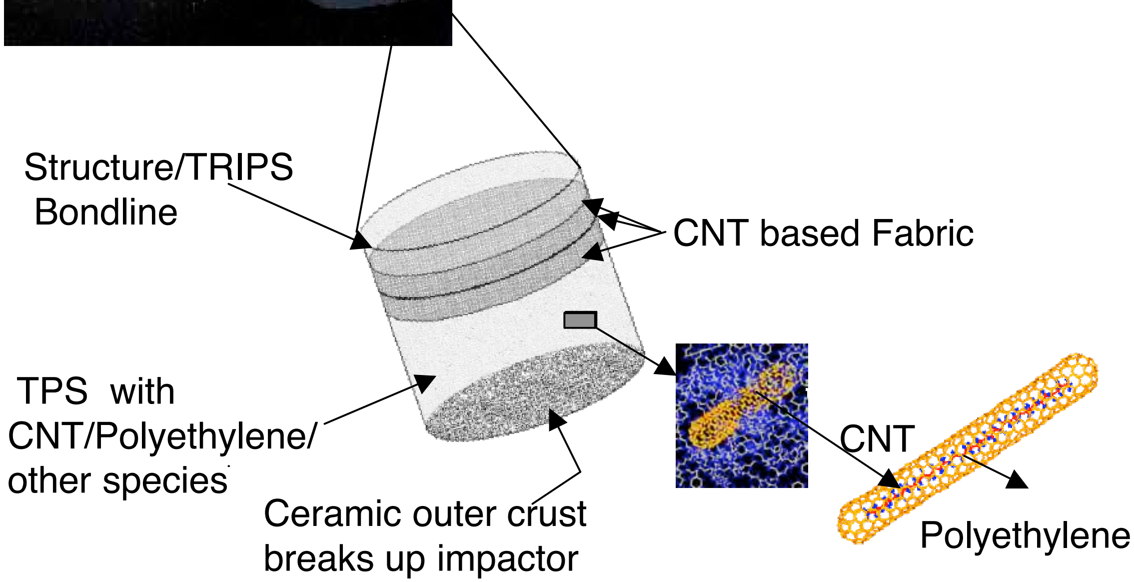


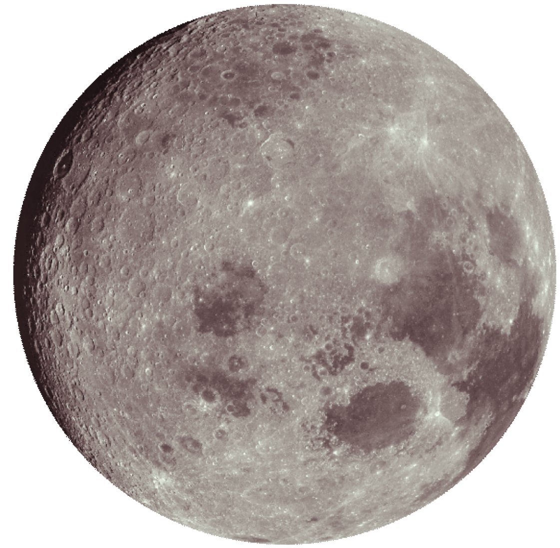
Evolved Antennas 97% Efficient
(vs 38% for Conventional)

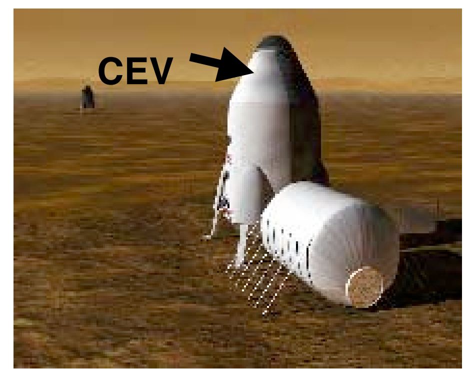
	Traditional Technology	Nano Enabled Technology
TubeSize	12 inches	1 inch
Instrument size	Dishwasher sized	Breadloaf sized
Instru. Power Use	~1000 Watts	~ 10 Watts
Instrument Mass	~ 500 kg	~5 kg

TRIPS Concept

Thermal, Radiation Impact Protective Shields (TRIPS)



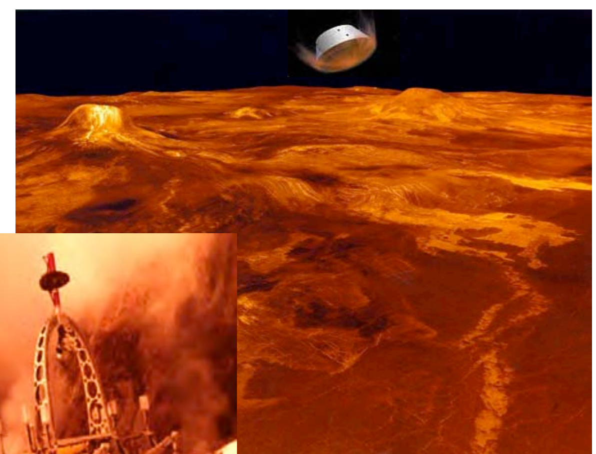




Goal: Multi-use TPS materials--One shield provides benefits of three => Reducing mass, while improving mission safety

Venus Surface Explorer

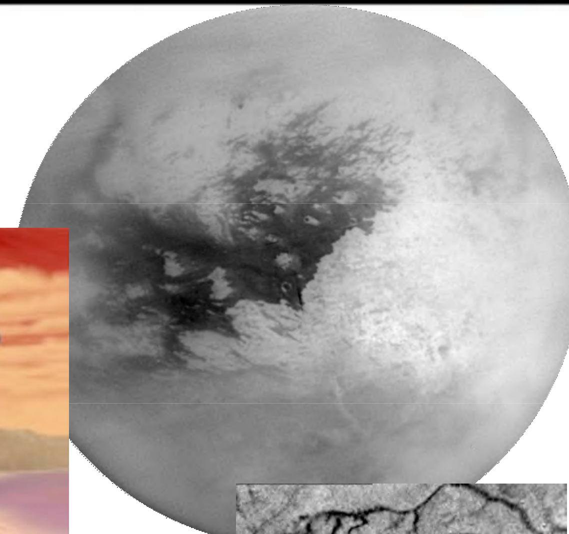
- **Habitability Thread**
  - Was there ever water on the surface of Venus?
- **Technology Challenges:**
  - High temperatures of ~500 degrees C, High Pressure: Surface 90 bars, Corrosive Chemicals
    - All require special attention to structure and design of surface vehicles, pressure vessels, electronics and surface mobility
  - Extreme entry velocity/very high heating rates in CO_2 atmosphere
    - Requires extreme environment thermal protection systems (TPS) and testing in relevant environments
  - Extreme depth
    - Requires special attention to entry probe design including pressure vessel structure to deal with > 100 bar pressures and thermal management of sensors, electronics and battery
    - Communications technology needed for data transfer from extreme depths

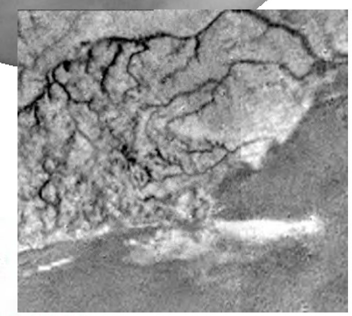


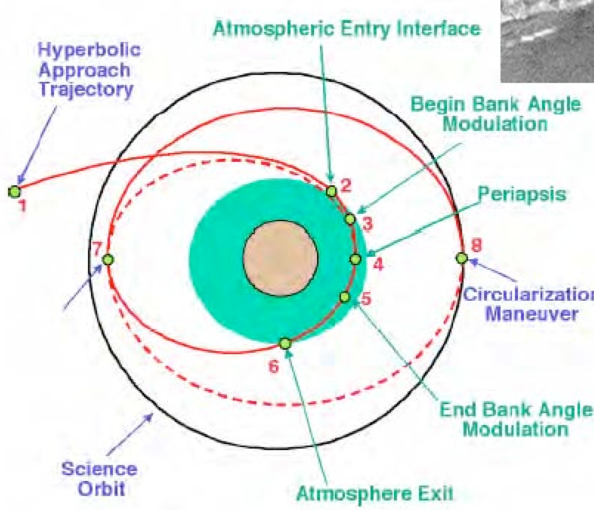
- **Potential Probes Solutions**
    - Carbon phenolic uses a very large mass fraction; new, lightweight materials, possibly strengthened with carbon nanotubes could reduce mass fraction substantially.
    - Innovations in robotic explorers will be needed to survive the caustic, corrosive heat and pressure.

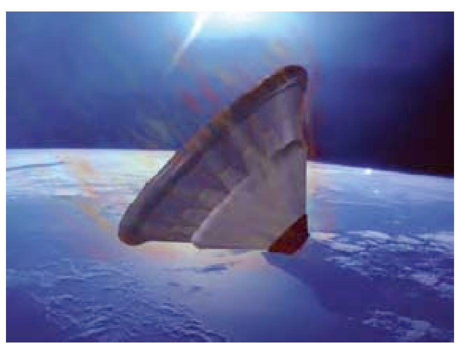
Titan Explorer

- **Habitability Thread**
  - What is the organic chemistry of Titan?
- **Technology Challenges:**
  - Possible aerial mobility
  - Extremely low temperatures
- **Potential Probe Solutions**
  - Entry environment system demonstrated by Huygens is adequate; no new development immediately required
  - Aerocapture entry system
    - Requires targeting precision and complex, robust software with continuous, rapid, autonomous adjustment: an advance on Deep Space 1 technology









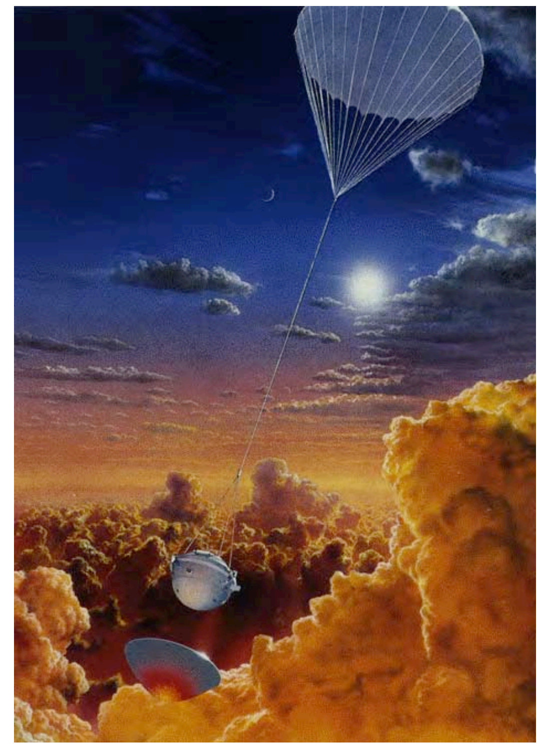
Comet Sample Return

- **Habitability Thread**
  - Could organics from comets have “seeded” Earth with organic building blocks of life or delivered Earth’s water?
- **Technology Challenges:**
  - Extremely low temperatures-70-90K
  - Sample acquisition
  - Cryogenic sample return/Earth entry
- **Potential Probe Solutions**
  - New nanostructured materials could greatly improve payload mass fraction and engineering margins for mission robustness

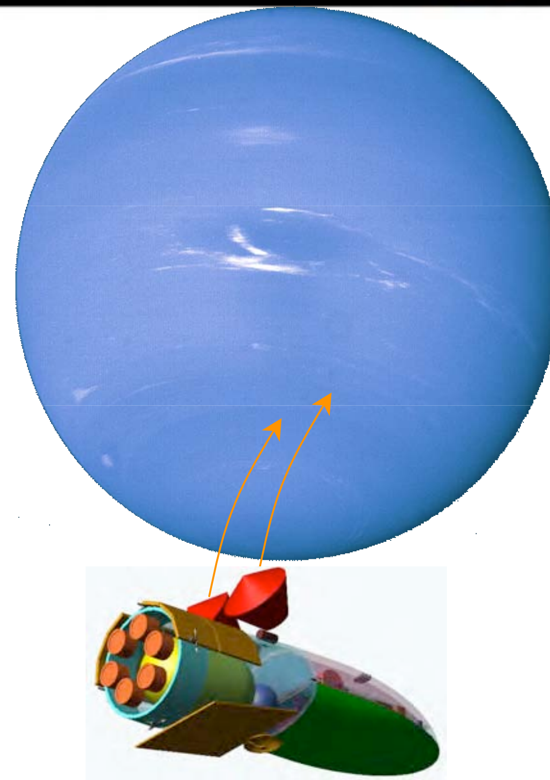
Sample Return capsule with nanostructured Reinjforced Carbon Carbon Heat Shield is 32 % lighter than baselined carbon phenolic heatshield

Jupiter Polar Orbiter with Probes

- **Architecture of solar systems thread**
  - What affects the formation of solar systems?
- **Technology Challenges:**
  - Extreme environment technologies (high temperature: 400C, high pressure: 100 bars)
  - Extreme entry velocity/heating rates in H_2/He atmosphere
  - Entry Probe technology
  - Extreme depth
    - Requires special attention to entry probe design including pressure vessel structure to deal with > 100 bar pressures and thermal management of sensors, electronics and battery
    - Communications technology needed for data transfer from extreme depths: Telecom link to 100 bars
  - Radiation environment
- **Potential Probe Solutions**
  - New high capability heat shield (to replace carbon phenolic) would be usable for a variety of missions
  - Any new materials or design would require validation in H_2/He atmosphere at appropriate temperatures.
  - Nano structured high pressure vessels would improve mass fraction
  - Evolved antennas which are small, lightweight and highly efficient could evolve to withstand 100 bars and may facilitate communications



Neptune Orbiter with Probes



- **Architecture of solar systems thread**
  - What affects the formation of solar systems?
- **Technology Challenges:**
  - Extreme environment technologies (high temperature, high pressure: up to 1000 bars
  - Extreme entry velocity/heating rates in H_2/He atmosphere
  - Entry Probe Technology
  - Extreme depth
    - Requires special attention to entry probe design including pressure vessel structure to deal with > 100 bar pressures and thermal management of sensors, electronics and battery
    - Communications technology needed for data transfer from extreme depths: Telecom link up to ≈ 100 bar
  - Science instrument miniaturization
- **Potential Probe Solutions**
  - Neptune probe requirements similar to Jupiter
  - Aerocapture requires adequate heat shield materials; new development would significantly enhance mission robustness
  - Aerocapture requires complex, robust software with continuous, rapid, autonomous adjustment: an advance on Deep Space 1 technology
  - Probe solutions could benefit from nano-enhanced approach